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ScienceDirect
Procedia Environmental Sciences 28 (2015) 783 – 788
Procedia Environmental Sciences

The 5th Sustainable Future for Human Security (SustaiN 2014)

Potential for subterranean termite attack against five bamboo species in correlation with chemical components

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Abstract

Bamboo has been a building material for centuries in Indonesia and Japan. Traditional buildings use bamboo to support walls or as an interior material. Recent changes in people's lifestyles and in architectural design have resulted in decreased use of bamboo. However, new housing materials made from bamboo have been developed and new building methods have also been proposed. This study was conducted to evaluate the potential for termite attack against five bamboo species, *Gigantochloa apus, G.atroviolacea, G.atter, Dendrocalamus asper, and Bambusa vulgaris.* The objectives of the study were to measure the chemical components of these five species in central Java and determine whether they deter attack by the subterranean termite *Coptotermes formosanus Shiraki.* A factorial experiment with a split plot design was applied with three replications. Tests of the five bamboo species indicated that extractive soluble in cold water was 5.91%; hot water was 7.70%–10.22%; toluene was 1.99%–7.49%; holocellulose was 73.54%–80.69%; ash rate was 1.47%–4.21%; solubility in NaOH 1% was 20.93%–29.47%. Cellulose in *Bambusa vulgaris* (53.34%) and nitrogen content of *G.apus* (0.33 %) were higher than those of *G.atrolviolascea*, *G.atter,* and *D.asper*. The highest lignin content was found in *G.atter* bamboo (27.33%). Termite damage was related to the chemical composition of the different bamboo species. The correlation between chemical component and termite activity test is also discussed.

Peer-review under responsibility of Sustain Society

Keywords: Bamboo; Subterranean termite; termite resistance; *Coptotermes formosanus* Shiraki

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Peer-review under responsibility of Sustain Society
doi:10.1016/j.proenv.2015.07.092

1. Introduction

Subterranean termites of the genus *Coptotermes* are important urban pest insects in tropical countries [1, 2]. Economic losses due to termite attack were estimated to be US$ 373 million in 2000 and losses are increasing each year. Economic damage caused by subterranean termites *Coptotermes formosanus* Shiraki annually is estimated to be about US$ 50 billion worldwide, and the United States alone spent US$11 billion to control the pest. This genus includes the most destructive pests in the world [3]. Termites cause serious damage to buildings and construction materials in Indonesia and Japan. However, no detailed studies on the biological degradation of bamboo by termites has been conducted so far. Two kinds of bamboo are often used as building material, and schools and traditional buildings often have bamboo in their structures. In addition to the damage to buildings, the social and ecological impacts caused by termite attack must also be considered [4].

Bamboo is widely grown and used as a construction material around the world, particularly in tropic region. At present, approximately 70 species and varieties of bamboo are grown and used in Indonesia [5,6]. In Semarang city, Central Java, bamboo is used as a building material and to produce mats, baskets, tools, handles, hats, traditional toys, musical instruments, and furniture. In the food sector, bamboo shoots are becoming more popular [7]. Buildings that feature bamboo are usually cheaper than wooden houses, and they are light, strong, and earthquake resistant, unlike brick or cement constructions. Five bamboos *Gigantochloa apus, G.atroviolacea, G.atter, Dendrocalamus asper, and Bambusa vulgaris* are exotic bamboos from Semarang city, Central Java .

Certain types of bamboo are grown for use in specific products, and additional products with higher quality may be developed by using a refined processing technology in the future [8]. One of the basic properties of bamboo, aside from its anatomy, is its chemical components. Some reports have indicated that the biodeterioration of bamboo depends on the extractable substances within it. Previous investigations mainly focused on the damage to bamboo caused by the attack of insect pests [9]. The objective of our study was to determine the relative resistance of five Indonesian-grown bamboo species to attack by Formosan subterranean termite (*Coptotermes formosanus* Shiraki). We investigated termite attack against five bamboo species with regard to their chemical content, which was measured by Japanese International Standard (JIS) methods [10]. Three-week laboratory feeding trials were performed as described in JIS E1-09. Samples of each of the five bamboo species were separately exposed to 165 termites (including15 soldiers), and termite mortality and wood mass loss of the samples were assessed.

There was no significant correlation between the chemical content of bamboo samples and their consumption by Formosan subterranean termite, although termites that fed on bamboo had higher mortality than those feeding on wood.

2. Materials and Methods

2.1. Materials

Samples of 2- to 3-year-old bamboo of five species (*Gigantochloa apus*, *G.atrolviolascea*, *G.atter*, *Dendrocalamus asper*, and *Bambusa vulgaris*) were obtained from culms harvested at the same time from plantation forests in Semarang City, Central Java, Indonesia. The test samples were taken from the center sections of internodes located 1, 4, and 8m from the base. After the wax layer covering the epidermis on the outer surfaces was removed with acetone, the segments were oven-dried at 60°C for 48 h and kept in plastic containers with calcium chloride–based absorbents.

2.2. Bamboo and Pine Wood Treatment Test

The termite tests were conducted according to JIS K-1571-2009. Samples (20 × 20 mm with a thickness of 4–10 mm) were prepared from each section. Formosan subterranean termites were obtained from a laboratory colony maintained at 28° ± 2°C and >85% relative humidity in the dark (termite breeding room). Each bamboo sample was placed on hard plaster (thickness of 5 mm) at the bottom of a cylindrical container (8 cm in diameter and 6 cm in height), and 150 worker termites and 15 soldier termites were introduced into each container. The assembled containers were placed on damp cotton pads to maintain sample moisture levels and kept in the termite breeding room for 21 days. At the end of the test, termite mortality was determined, and the mass loss of the test sample after termite attack was calculated based on the differences in the initial and final oven-dried (60°C, 48 h) masses. Tests for each section were done in triplicate. Sapwood blocks (20 × 20 × 10mm) of Japanese red pine (*Pinus densiflora* Sieb. et Zucc.) were used as controls. This container was kept at room temperature in the dark. Observations were conducted every 2 days for the 3 weeks of the test periods. We put steril aquadest to cotton to keep temperature if the cotton dries.Termite mortality rate and sample weight loss were recorded.

$$\text{Sample weight loss} = \frac{ODS1-ODS2}{ODS1} \times 100\% \quad (1)$$

where ODS1 is the oven-dried sample before the test, and ODS2 is the oven-dried sample after the test.

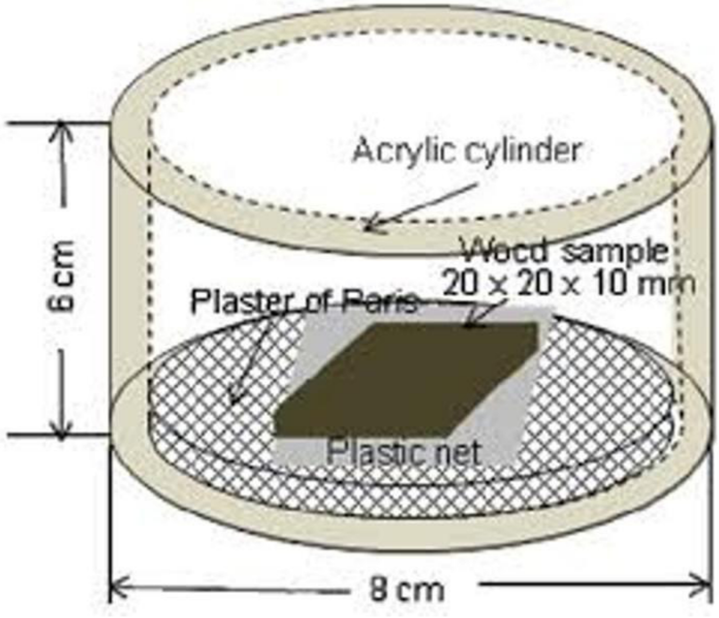

Fig. 1. Bamboo and Pine Wood Treatment Test with JIS (Japanese International Standard)

2.3. Natural Chemical Component

Determination of soluble chemical components naturally present in the bamboo was based on cold and hot water extraction according to ASTM D1110-56 [11]. Additional ASTM [11] procedures were undertaken, including soluble alcohol benzene extraction (ASTM D1105-96) and testing for holocellulose (ASTM D1104-56), cellulose (ASTM D1103-60), and lignin (ASTM D110-84). Nitrogen content was quantified by using Kjeldahl nitrogen (1883) procedures [12].

3. Results and Discussion

After 3 weeks of exposure to subterranean termites in the laboratory, sample weight loss and termite mortality were determined (Table 1). Based on sample weight loss and termite mortality, *D.asper* was more resistant to termite attack than *B.vulgaris*, *G.atter*, *G.atrolviolascea*, and *G.apus*.

Table 1. Sample weight loss and subterranean termite *Coptotermes formosanus* Shiraki mortality infive bamboo species and the pine wood control.

Species	Mean mass loss (g)	Mean mass loss (%)	Termite mortality (*T*)
Dendrocalamus asper (Betung)	0.28 ± 0.85	5.3 ± 15.90	56
Bambusa vulgaris (Ampel)	0.10 ± 0.31	8.22 ± 24.65	13
Gigantochloa atter (Legi)	0.16±0.49	8.74±26.22	55
Gigantochloa atrolviolascea (Wulung)	0.08±0.26	5.73±17.19	21
Gigantochloa apus (Apus)	0.11±0.33	6.85±20.57	17
Pinus densiflora (Sugi)	0.18±0.53	12.86±38.60	9

Subterranean termites feeding on *D.asper* had higher mortality than those feeding on the other four species and the pine wood, but none of the bamboo species with stood termite attack. This finding confirms that bamboo is a perishable timber that is generally not resistant to termite attack [13]. However, seasonal variation in bamboo growth or harvest may also have some effect on termite resistance, possibly due to changes in chemical composition within the plants [14]. Differences in feeding on bamboo may also be due to variations in chemical composition between bamboo species [15].

Table 2. Weight loss of wood and bamboo samples and termite mortality.

Species	*3.1.1. N*	Subset for α= 0.05			
		1	2	3	4
Bambusa vulgaris	3	1.19			
Pinus densiflora	3	1.20			
Gigantochloa atrolviolascea	3		1.43		
Gigantochloa apus	3		1.50		
Gigantochloa atter	3			1.70	
Dendrocalamus asper	3				5.05
Sig.		1.00	0.86	1.00	1.00

As shown in Table 2, the two most resistant bamboo species were *D.asper* and *G. atrolviolascea*, which demonstrated significantly greater resistance to subterranean termite attack than *G. apus*, the most susceptible species of bamboo. *Bambusa vulgaris* and *G.atrolviolascea* had intermediate termite resistance.

Table 3. Comparison of bamboo species based on cold-water, hot-water, and toluene extractions.

Bamboo species	Toluene (%)	Cold water (%)	Hot water (%)
Dendrocalamus asper (Betung)	7.49	11.34	9.58
Bambusa vulgaris (Ampel)	1.99	8.81	10.22
Gigantochloa atter (Legi)	3.31	8.25	9.63
Gigantochloa atrolviolascea (Wulung)	4.51	5.91	7.70
Gigantochloa apus (Apus)	3.39	7.88	8.18

Data in Table 3 focus on the extractable substances that fill cavity cells, fiber cell wall, and cell pores in bamboo. Hot-water (7.49%) and cold-water extractives (11.34%) of *D.asper* bamboos exceeded those of *B.vulgaris* (8.82%), *G.atter* (8.25%), *G.atrolviolascea* (5.91%), and *G.apus* (7.88%). The number of alcohol-soluble extractive substances from *D.asper* benzene was relatively higher compared with *B.vulgaris*, *G.atter*, *G.atrolviolascea*, and *G.apus*, and may suggest that the bamboo is resistant to termite attack. Alcohol soluble extractive substances benzene is *D.asper*, then this bamboo is more resistant to termite attack than other bamboos.

Table 4. Comparison of bamboo based on holocellulose, NaOH, and ash.

Bamboo species	Holocelulose(%)	NaOH (%)	Ash (%)
Dendrocalamus asper (Betung)	75.66	29.47	3.55
Bambusa vulgaris (Ampel)	80.69	23.80	4.21
Gigantochloa atter (Legi)	74.37	24.11	1.47
Gigantochloa atrolviolascea (Wulung)	73.54	20.93	1.57
Gigantochloa apus (Apus)	75.24	20.93	1.57

Tests results indicated that holocellulose and ash of *B.vulgaris* (80.69%, 4.21%) were higher than those of *D.asper* (75.66%, 3.55%), *G.atter* (74.37%, 1.47%), *G.atrolviolascea* (73.54%, 1.57%), and *G.apus* (75.24%, 1.57%). Bamboo with a higher mineral content was more likely to be attacked by termites asa nutrient-rich food source. The NaOH content of *D.asper* (29.47%) was higher than that of *B.vulgaris* (23.80%), which in turn was higher than the NaOH content of *G.atter* (24.80%), *G.atrolviolascea* (20.93%), and *G.apus* (20.93%).

Termite damage was studied in relation to the chemical composition of the bamboo samples [16, 17]. The nitrogen content in bamboo was previously found to be directly related to termite damage. The quantity of lignin and ash present in bamboo also influenced termite damage and played a significant role in the bamboo's termite resistance [18].

Table 5. Comparison of bamboo species based oncellulose, lignin, and nitrogen content.

Bamboo species	Cellulose (%)	Lignin (%)	Nitrogen (%)
Dendrocalamus asper (Betung)	51.20	24.51	0.32
Bambusa vulgaris (Ampel)	53.34	21.95	0.26
Gigantochloa atter (Legi)	49.88	27.33	0.12
Gigantochloa atrolviolascea (Wulung)	49.59	26.99	0.32
Gigantochloa apus (Apus)	49.60	24.85	0.33

As shown in Table 5, the lignin content of bamboo *G. Atter* was higher than that of *G.atrolviolascea*, *D.asper*, and *B.vulgaris*, which may also help to explain the higher resistance of this species to termite attack. The main components of the bamboo cell walls are cellulose and lignin. The highest cellulose content was found in *B.vulgaris* compared with *D.asper*, *G.atter*, *G.atrolviolascea*, and *G.apus*, which were heavily damaged by termites. The results showed that the nitrogen content was highest in *G.apus*, followed by *D.asper*, *G.atrolviolascea*, *B.vulgaris*, and *G.atter*. A high nitrogen content is preferred by termites, and the nitrogen content in bamboo may be directly related to termite damage. Feeding on low molecular weight celluloses has previously been shown to have a detrimental effect on the large-sized symbiotic protozoa of *C. formosanus*, and feeding on starch and sugars generally has a detrimental effect on protozoa of *C.formosanus* workers [19]. These results may indicate a negative effect of food on the feeding activity of termites. Termites attacked only the inner radial sections of the samples. Parenchyma cells in bamboo are highly dense inthe innerculm, sclerenchymatous fibers, and bundle sheath, but they are highly dispersed in the outer culm [20].

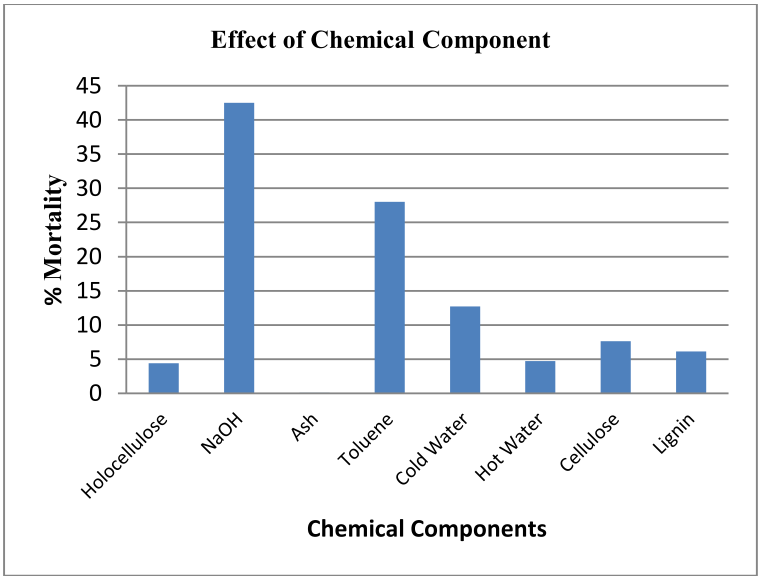

Fig. 2. Chemical components of bamboo species in Indonesia and associated termite mortality.

Lignin is a tough cell wall component that can be damaged by bamboo-destroying organisms, but a high lignin content leads to low termite damage. Lignin interferes with digestion in the termite gut by binding both substrates and carbohydrate digestive enzymes. High-nutrient food is preferred by termites, and the nutrient content in bamboo may be directly related to termite damage [21, 22]. Higher ash content reduces the food value of bamboo for termites because it is not absorbed in the gut body and passes through. Some minerals in bamboo can have a toxic effect on the pests or disturb their physiology [23, 24]. In addition, the presence of toxins in bamboo inhibits digestion, and these toxins have been termed ddigestibility reducers. The possibility exists is that seasonal variation could influence the chemical content of bamboo. Further research is needed to better define those circumstances and to assess other bamboo species as well as the influence of harvest timing on their chemical composition. In conclusion, the toxic content of bamboo may be inversely related to termite damage.

Acknowledgements

We would like to thank Director General of Higher Education, Ministry of National Education and Culture Republic Indonesia for financial support (Competitive Research Grant No. 563/UN37.3.1/ LT /2014). Gratitude is also extended to the Semarang State University in Indonesia, and to RISH, Kyoto University in Japan for assistance and support in the research.

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